Comment on "Coronal mass ejections, interplanetary ejecta and geomagnetic storms" by H. V. Cane, I. G. Richardson, and O. C. St. Cyr

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[1] *Cane et al.* [2000] claimed that the majority of the interplanetary ejecta (IP) in their study arrive at 1 AU earlier than is predicted by the empirical model of *Gopalswamy et al.* [2000]. We show that this claim is not valid because the transit times they used are not for ejecta, but for a "mixed bag" containing sheaths ahead of the IP ejecta and some ejecta.

[2] The empirical CME arrival (ECA) model of *Gopalswamy et al.* [2000] is based on the effective IP acceleration, a (ms^{-2}), which was found to be a function of the CME initial speed (u in km s^{-1}): $a = 1.41 - 0.0035u$. Using a in the kinematic relation, $S = ut + \frac{1}{2}at^2$ one can solve for t, the transit time with S = 1 AU (the distance traveled by the CME). On the basis of a scatter plot between the transit times of IP ejecta and the speed of the associated white-light CMEs, *Cane et al.* [2000] claimed that, "the majority of the ejecta in our study arrive earlier than is predicted by the *Gopalswamy et al.* [2000] model." Figure 1 shows the ECA model curve from *Gopalswamy et al.* [2000] along with the *Cane et al.* [2000] data points. Indeed the majority of the data points are below the ECA model curve as *Cane et al.* [2000] had concluded. An improved ECA model [*Gopalswamy et al.*, 2001] obtained by minimizing projection effects also confirms the claim of *Cane et al.* [2000] (see Figure 1). This is puzzling because the data used by the ECA model and *Cane et al.* [2000] come from an overlapping time period.

[3] We suspect that *Cane et al.* [2000] might have incorrectly identified sheaths of IP shocks as ejecta for a large number of cases because shocks arrive ahead of the driving ejecta [*Borrini et al.*, 1982]. *Cane et al.* [2000] identified their IP ejecta "by considering a number of ejecta signatures including solar wind plasma, magnetic field and energetic particle observations from the IMP 8, WIND, and ACE spacecraft." *Cane et al.* [2000] also noted that, "ejecta generally produce measurable depressions (>~0.5%) in the cosmic ray intensity measured by the guard counting rate which are reliable indicators of the presence of ejecta." Cosmic ray depression (Forbush decrease) has two steps, one immediately behind an IP shock and the other at the driving ejecta [*Barnden*, 1973]. Since *Cane et al.* [2000] do not talk about the two-step decrease anywhere, we think that they might have identified just the first step, which marks the beginning of the sheath, and called it ejecta in many cases. For ejecta with shocks, this will underestimate the ejecta arrival by the standoff time. For ejecta without shocks, cosmic ray decrease will have only a single step that marks the ejecta [see, e.g., *Zhang and Burlaga*, 1988]. We think that the small number of low-speed events that have transit times close to the ECA model prediction may in fact be real ejecta. There may also be other real ejecta if *Cane et al.* [2000] used signatures such as solar wind plasma and magnetic field, rather than cosmic ray depression. Single-step depression can also be produced when the spacecraft passes through a shock flank without passing through the ejecta. In this case, the sheath will be counted as ejecta. Since the data points of *Cane et al.* [2000] were not distinguished by the method of identification, it is hard to tell sheath and ejecta apart. Thus the data points in Figure 3 of *Cane et al.* [2000] constitute a mixed bag, most corresponding to the arrival time of shock sheaths and some to that of ejecta. While the title of the relevant section of *Cane et al.* [2000] is "Transit times of ejecta," the caption to their Figure 3 talks about "Disturbance transit times." An

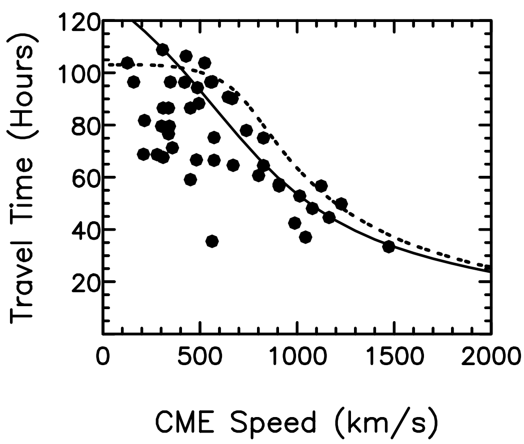

Figure 1. "Ejecta" transit times and CME initial speeds from *Cane et al.* [2000] along with the ECA model curves of *Gopalswamy et al.* [2000] (solid) and *Gopalswamy et al.* [2001] (dashed).

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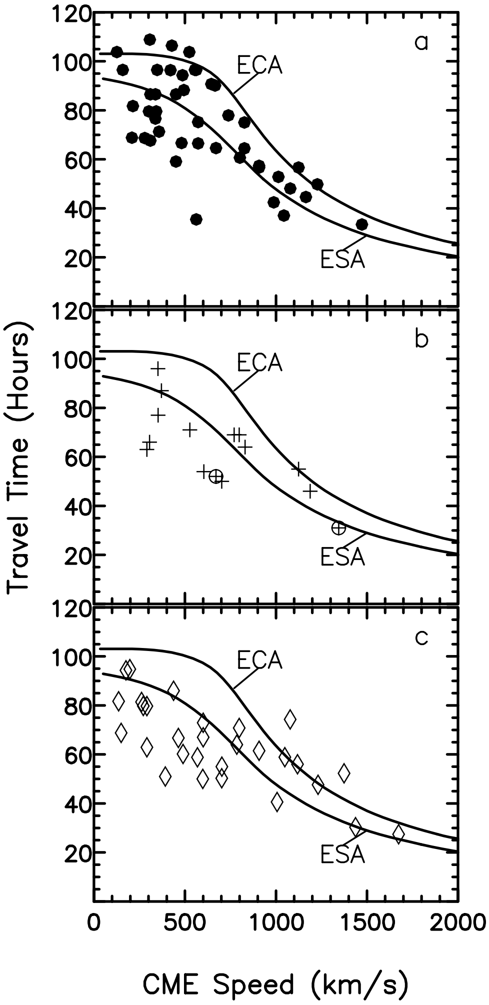

Figure 2. ECA and ESA model curves with (a) "ejecta" transit times and CME initial speeds from *Cane et al.* [2000], (b) shock transit times and CME initial speeds from *Zhang et al.* [2003] (two of the close-to-limb events (W77 and W80) are circled), and (c) transit times and CME initial speeds for a set of shocks driven by magnetic clouds.

IP disturbance could be a shock, sheath, or ejecta. Therefore, it is ambiguous as to what *Cane et al.* [2000] refer to as "transit times of ejecta."

[4] The ECA model can be extended to an empirical shock arrival (ESA) model by exploiting the shock-piston relationship known from gas dynamics: the ratio of the position of the shock front to the position of the driving piston is $(\gamma + 1)/2$, where γ is the ratio of specific heats [see, e.g., *Landau and Lifshitz*, 1987]. The ESA curve is plotted on the *Cane et al.* [2000] data points in Figure 2a. The *Cane et al.* [2000] data points are clearly scattered around the ESA curve suggesting that these points represent shock transit time, rather than the ejecta transit time as claimed by *Cane et al.* [2000]. The shock transit times of 15 disk events reported by *Zhang et al.* [2003] also cluster around the ESA curve, but well below the ECA curve (Figure 2b). The transit times of a different set of IP shocks driven by magnetic clouds (http://lepmfi.gsfc.nasa.gov/mfi/mag_cloud_publp.html) also resemble the situation in Figure 2a.

[5] If white-light CMEs were compared with ejecta (not sheaths) at 1 AU, it has been shown that the CME arrival can be predicted within ±10.7 hr [*Gopalswamy et al.*, 2001]. An ideal model would reduce this uncertainty to zero, but no such model exists at present. Now, let us look at the claim of *Cane et al.* [2000] that "there is a large scatter in the transit times, indicating that CME speeds are not particularly reliable predictors of transit times." It is true that varying solar wind speeds and other factors such as preceding CMEs can cause scatter in the ejecta transit times. Scatter can also occur due to incorrect identification of white-light CMEs corresponding to ejecta at 1 AU. However, when sheaths and ejecta are lumped together as *Cane et al.* [2000] did, it is difficult to separate inherent scatter in the data from the artificial scatter due to incorrect identification of ejecta.

[6] To summarize: (i) The statement by *Cane et al.* [2000] that the majority of the ejecta in their study arrive earlier than is predicted by the *Gopalswamy et al.* [2000] model is incorrect because they included a large number of shock sheath events as well as ejecta in their data set. Since they did not specify the method of identifying the IP ejecta (plasma, magnetic field, or cosmic ray decrease) for the events in their Figure 3, we suspect that they might have compared a "mixed bag" of transit times with the ECA model prediction. (ii) Since most of the data points of *Cane et al.* [2000] follow the empirical shock arrival model curve, we think that most of the transit times they obtained may not correspond to the IP ejecta, but to IP shocks. (iii) One has to separate the ejecta and shock travel times before assessing the extent of scatter in the observed transit times.

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